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OPTIMISATION OF 3D PRINTING PARAMETER FOR IMPROVING MECHANICAL STRENGTH OF ABS PRINTED PARTS

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ABSTRACT

Three-dimensional (3D) printer is a computer-aided manufacturing (CAM) device that creates 3D objects. The principle of 3D printing involves a digital model which is turned into a solid 3D physical object by adding the material layer by layer. The objective of this study is to determine the optimum combination of a 3D printing machine parameter setting, such as printing temperature, speed and resolution, to produce the highest flexural strength. Taguchi Method and Analysis of Variance (ANOVA) were applied to get the best process parameter combination and to identify the most affective parameter on the flexural strength. The result from this study demonstrated that the optimum setting for the 3D printer (Vagler V-821) machine had printing temperature of 240 °C, printing speed of 30 mm/s and printing resolution of 250 µm. The result from the Taguchi Method and ANOVA concluded the most effective effect on the flexural strength was printing speed, followed by printing resolution and printing temperature.

Key words: 3D printing, ABS, ANOVA, Taguchi method and flexural strength.

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1. INTRODUCTION

A three-dimensional (3D) printing is an advanced process of translating a digital file into 3D solid objects. 3D printing is a technology that develops objects by using addictive process without the need for a cutting tool or mold. Fused Deposition Modelling (FDM) is an additive

manufacturing technology that use a heating and extruding thermoplastic filament to build parts up layer-by-layer. FDM is an efficient and reliable process. However, most products that are printed by using FDM have poor dimensional accuracy, surface finish and strength with less compatible materials available [1]. The most frequently used thermoplastic polymers are acrylonitrile–butadiene–styrene (ABS) and polylactic acid (PLA), but currently Polyethylene terephthalate (PET), Nylon, polycarbonate (PC) and graphene are also considered.

The performance of parts produced by a FDM machine is controlled by the process parameters, such as the air gap between adjacent tracks, raster angle, raster width and thickness of deposited layers [2]. The most common parameters studied by other research were infill, printing axis, layer thickness, deposition angle, delay time and others [3-6]. Luzanin et al. [3] studied the effect of layer thickness, deposition angle and infill on the maximum flexural force. They found that the flexural force was mainly affected by layer thickness and the relation between deposition angle and infill was significant. On the other hand, Tontowi et al. [4] investigated the highest tensile strength and the lowest dimension error, based on the optimum parameters (layer thickness, temperatures and raster angles). The study showed that the tensile strength of printed polylactic (PLA) part was mostly affected by layer thickness, while dimension error was caused by raster angle. To date, no research was reported on the 3D printer parameter settings, such as printing speed and resolution on the bending strength of the printed parts.

The main objective of this paper is to find the optimum printing parameters for FDM machine, such as printing temperature, speed and resolution that produce ABS parts with high flexural strength through the Taguchi Method. The most important parameters that affect 3D printing part strength and the interaction between the parameters will be identified.

2. EXPERIMENTAL

2.1. Specimen

Samples used in the experiment were printed by using the Fused Deposition Modelling (FDM) 3D printer, Vagler V-821. The material used was acrylonitrile–butadiene–styrene (ABS). A 20% honeycomb type infill pattern was chosen. The ABS specimens were printed at different printing temperatures, speeds and resolutions. Table 1 shows the printing parameters used in this experiment.

Table 1 Printing parameter

Printing Temperature (°C)	Printing Speed (mm/s)	Printing Resolution (µm)
220	30	150
240	70	200
260	120	250

2.2. Mechanical Testing

Three-point bending strength measurement was done on rectangular bars (3.2 mm x 12.7 mm x 125 mm) by using a universal testing machine (Instron 5982), following the ASTM D790. A span of 63 mm and cross head speed of 2 mm/min were used. The value of the flexural stress was calculated by using Equation 1.

$$\sigma = \frac{3\,FL}{2\,bd^2} \qquad (1)$$

Where, F is the force at sample break (N), L is the support length (mm), b is the width of the sample size (mm) and d is the thickness of the sample size (mm).

Analysis of variance (ANOVA) was performed on the obtained result by considering the printing parameters as factors and flexural stress as response. ANOVA was used to identify the statistical significant process parameter in the experiment and determine the contribution of each process parameter towards the output characteristics [2].

2.3. Design of Experiment

Taguchi Method is a technique that provides an efficient method for design optimisation. The experimental design that use the Taguchi Method allows the study of interaction between different parameters. Taguchi Method incorporates the orthogonal array, giving different parameter combinations and their levels for each experiment [2, 7]. For this experiment, the L9 array was selected and the levels of the parameter are displayed in Table 2. Each parameter was considered to have an independent effect or no effect on their interactions. The main effect analysis was performed based on the average output value (flexural stress) at each parameter level. The S/N ratio was used to represent a performance characteristic. Higher signal- to-noise (S/N) ratio was preferred because a smaller variance around the target value was produced at greater S/N ratio [2]. Therefore, the larger-the-better S/N ratio based on the flexural stress was chosen by using the following equations:

$$\text{MSD}=\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2} \quad (2)$$

$$\text{S/N} = -10\ log_{10}(\text{MSD}) \quad (3)$$

Where, MSD is the mean square deviation for the output characteristic and commonly known as quality loss function, n is the number of experiments, y_i is the value of responses (which is flexural strength).

Then, possible combination of optimum parameters was predicted by using the main effect and ANOVA. ANOVA was used to identify which parameters have significant effects on the quality characteristics and the contribution of each process parameter towards the output characteristics.

Table 2 Levels of process parameter for 3D printed ABS specimens

Experiment No.	**Parameter Level**		
	Printing Temperature (°C)	**Printing Speed (mm/s)**	**Printing Resolution (µm)**
1	220	30	150
2	220	70	200
3	220	110	250
4	240	30	200
5	240	70	250
6	240	110	150
7	260	30	250
8	260	70	150
9	260	110	200

3. RESULT & DISCUSSION

Table 3 shows the flexural stress results and S/N ratio for all nine ABS printed specimens. Each specimen was represented by each experiment of the orthogonal array, as shown in Table 2. Specimen printed at 260 °C, 30 mm/s and 250 µm (Experiment 7) showed the highest flexural stress.

Table 3 Flexural stress and S/N ratio of printed ABS specimens

Experiment No.	Flexural Stress (Mpa)	S/N Ratio
1	35.86	31.09
2	31.96	30.09
3	34.21	30.68
4	35.97	31.12
5	37.62	31.51
6	36.07	31.14
7	38.73	31.76
8	31.06	29.84
9	33.95	30.62

The mean S/N ratio for each control factor (printing temperature, speed and resolution) for Level 1, Level 2, and Level 3 were calculated by using the flexural strength data from Experiment 1-3, Experiment 4-6, and Experiment 7-9, respectively, from Table 1. From the data shown in Table 4, printing speed had significance effect over flexural strength, followed by printing resolution and printing temperature. At high printing speed, the machine will vibrate more; thus, causing inaccurate details and geometrical shape. In addition, at high printing speed, the first layer does not have enough time to cool down fully before the second layer was printed out on top of it. So, the bonding between layers was poor, and thus reduced the strength of the printed specimen [8-9].

Table 4 Response table for S/N ratio larger is better

Level	Temperature	Speed	Resolution
1	29.72	29.92	29.74
2	29.90	29.68	29.72
3	29.75	29.77	29.91
Delta	0.18	0.24	0.20
Rank	3	1	2

The main effects plot for flexural stress based on the S/N ratio result is shown in Figure 1. It can be seen that the best combination of parameters for the optimum flexural strength was printing temperature of 240 °C, printing speed of 30 mm/s and printing resolution of 250 µm.

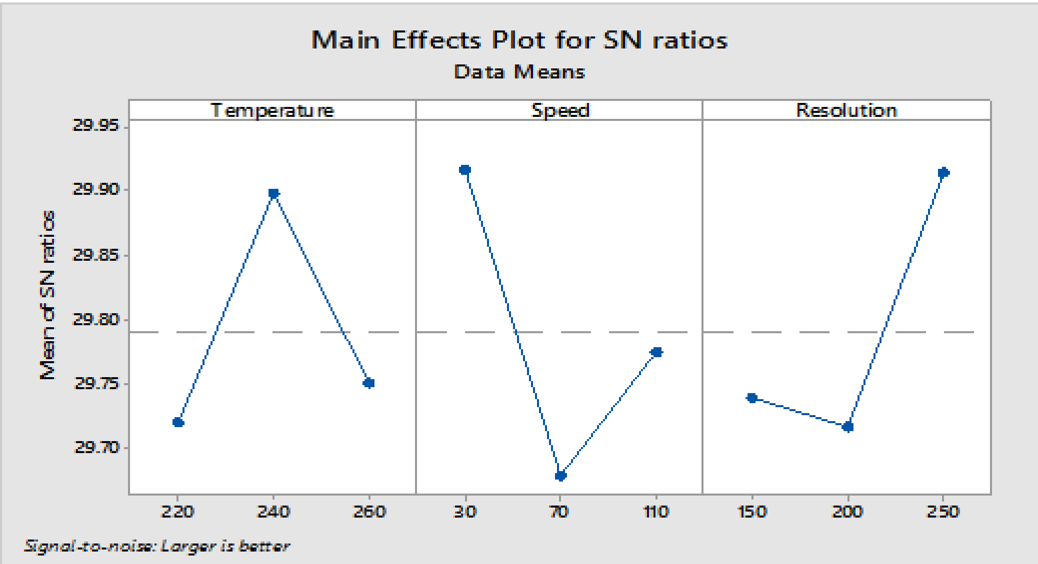

Figure 1 Main effect plots for S/N ratios

Table 5 ANOVA for flexural stress of printed ABS

Source	DF	Sum of Square	Mean Square	Ratio, F	Contribution (%)
Temperature	2	10.701	5.35	1.39	21
Speed	2	16.838	8.419	2.19	34
Resolution	2	14.882	7.441	1.94	30
Error	2	7.676	3.838		
Total	8	50.097			

Table 5 shows the ANOVA results for flexural stress. It was found that all three parameters (printing temperature, speed and resolution) had significant effects to produce the printed ABS specimens with high strength. However, the contribution order for flexural stress was printing speed, followed by resolution and temperature.

4. CONCLUSIONS

An ABS part was printed by using FDM machine with varying printing parameters, such as printing speed, resolution and temperature. The mechanical strength of the printed part was investigated. Result from Taguchi Method analysis showed that the printing temperature of 240 °C, printing speed of 30 mm/s and printing resolution of 250 μm were the optimum conditions to print the ABS part with highest flexural strength. In addition, both the Taguchi Method and ANOVA found that printing speed had a significant effect over flexural strength, followed by printing resolution and printing temperature.

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